DOCUMENT RESUME

ED 184 819 **SE 030 360**

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TITLE Extraterrestrial Life: Processes, Implications, and Applications.
PUB DATE Oct 79
NOTE 16p.; Paper presented at the meeting of the National Association of Biology Teachers (New Orleans, LA, October 27, 1979).

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Biology; *Instructional Materials; Science Education; *Science Fiction; Secondary Education; *Secondary School Science
IDENTIFIERS *Extraterrestrial Life; Origin of Life

ABSTRACT

Provided are background materials relating the study of extraterrestrial life to common biological principles. A history of the creation of the sun and earth is included, as well as a summary of one current theory regarding the origin of life on earth. Relationships are identified regarding possible origins of life on other planets. Factors emphasized as major parameters of favorability for life are stellar mass, planetary mass, presence of liquid solvent, and acceptable amounts of radiation reaching the surface. Universal biological schemes and concepts are reviewed which may be applied in predicting what extraterrestrial life would be like under differing conditions. (CS)

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EXTRATERRESTRIAL LIFE: PROCESSES, IMPLICATIONS, AND APPLICATIONS

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PRESENTED TO:

THE NATIONAL ASSOCIATION OF BIOLOGY TEACHERS CONVENTION
Saturday, October 27, 1979
New Orleans, Louisiana

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ABSTRACT

Interest in extraterrestrial life has always been high, but it is especially keen due to recent scientific advances and the renaissance of popular science fiction in the movies. This interest can be exploited by the classroom biology teacher as a lead-in to many biological principles. By undertanding that life on Earth, and possibly on other planets, is organized according to rational and observable principles, the student can develop a more systematic and objective attitude towards living things.

In an age when science so closely fulfills science fiction, serious study and contemplation of life on other worlds has again become the business of many reputable scientists. This new extraterrestrial (ET) respectability is in part due to two recent realizations. The first, on the part of astronomers, is that planets in general and Earth-like planets in particular are probably not as unique as was once thought. The second, made by biologists and biochemists, is that life as a process is probably an inevitable extention of non-living planetary systems, given the necessary conditions.

Such life need not be intelligent as we understand intelligence. Intelligence itself is a relatively recent evolutionary adaption, one of the many kinds of means to achieve the final end of reproduction and survival. Perhaps we tend to think of extraterrestrial life as intelligent life because we ourselves have had trouble coping with the kind of world our intelligence has wrought:

> Throughout all our history we have pondered the stars and mused whether mankind is unique or if, somewhere out there in the dark of the night sky, there are other beings who contemplate and wonder as we do, fellow thinkers in the cosmos. Such beings might view themselves and the universe differently. Somewhere else there might exist exotic biologies, technologies and societies.....In the deepest sense the search for extraterrestrial intelligence is a search for ourselves.[14]

For the classroom teacher of science, the study of extraterrestrial life offers a new and interesting perspective. We can present key biological concepts in a way both meaningful and interesting to individual student. We are in fact making use of the interest previously engendered by science fiction books and movies. At the same time, we can correct the many misconceptions and inaccuracies present in these media (especially in the older works).

To fully understand alien life systems, we must first understand how ours came about. The student must be encouraged to look at the world around

him and think "Where did it all come from?".

Our tiny blue planet is an island on the shores of a vast sea of stars. When you touch the palm of your hand, you are feeling a substance produced long ago in a star. In the central furnace of that star, the atoms that make up your hand were built from hydrogen, the fuel of the starfire. As the star burned through its long lifetime, the hydrogen underwent fusion reactions that eventually led to atoms of carbon, oxygen, and nitrogen. Deep inside that long-dead star the atoms that would one day become you were made, until one day the star's active life began to end.

Eventually, through natural processes, the star exploded as a super-nova. The explosion was white-hot, too intense for the human eye to perceive. The outer layers of the star, enriched with atoms of carbon, hydrogen, oxygen, nitrogen, iron, silicon, and all the other elements that would eventually make up the Earth and its inhabitants, were blown away into space. The central dead core of the star was left to cool and die.

The expanding cloud of stellar debris, still shining from the heat of the explosion, travelled outward in all directions. Eventually, parts of its would combine with expanding clouds from other super-nova. As is travelled outwards, it also gathered new hydrogen fuel from the interstellar medium. In some places, dusty whirlpools of debris began to form.

At the center of the spiral, the newly gathered hydrogen and some of the dead star's dust (actually the dust of thousands of dead stars) begins to glow as gravity compresses the mass together. A new star, our Sun, begins to shine. Soon, the factors of mass, hydrogen content, and pressure are right and the hydrogen begins to undergo fusion. Around the Sun, other parts of the dusty cloud have also begun to gather together.

These dusty accretions are much smaller than the Sun, and although they form globes they do not have enough mass or gravity to ignite as stars. Only the largest, one day to be called Jupiter, comes near to the required size. The new globes will never shine by themselves, for they are the planets.

The planets grow ever fatter, gathering smaller planetoids by impact or as moons. Immense amounts of water and gases are trapped in the rocks of the various planets.

The third planet from the Sun, Earth, gathers such gases as hydrogen, helium, methane, ammonia, and water from the great cloud that is becoming our Solar System. The Earth is soon covered by a dense, thick atmosphere under which life could never form. Luckily for us, it has also captured a large moon, Luna, which pulls off the lighter gases hydrogen and helium by tidal action. The Moon, circling the Earth like a giant vacuum cleaner, removes most of the dense atmosphere. Life is now possible.

At the center of the Earth, dense iron and nickel have formed a metallic core which generates a magnetic field when spun. The Earth is covered in this magnetic field like an egg in its shell, and the field acts to deflect or absorb much of the radiation reaching the Earth before it can approach the surface. On the barren, damp surface oceans gather from condensing water vapor as the surface cools. The stage is now set for life.

Gases are present in the atmosphere from which the chemicals of life can be made. All it takes is a little energy, in the form of lightning, volcanic or geothermal heat, or perhaps ultraviolet radiation, and the chemicals begin to link together. This linkage may occur both on the rocky surface or in the air itself, and soon the chemicals are being washed by rainwater into the oceans and fresh water bodies of the primitive Earth. They form a primitive "soup", a solution of concentrated amino acids, carbohydrates, and nucleic acids.[8]

In the "soup", the likelihood of favorable life-producing collisions is greatly increased. The proteins, for example, when formed in aqueous solution cling together to form closed bubbles called microspheres. In these bubbles, the atoms and molecules that will make up the first living terrestrial organisms are brought into final juxtaposition. Over millions of years, and in millions of places, nature builds strange new chemicals made of thousands of atoms. Almost all of them fail to do anything at all. But finally chance, luck, and unlimited time work together to form one that is able to reproduce itself. The new molecule, precursor of Mozart, moth, and moss, begins to feed upon the soup from which it came.

Although the natural processes which produced the soup still function, the new living molecules are hungry and soon deplete the supply. Soon after that, they probably begin to consume each other. Limited resources force evolution to begin, as competition begins to favor the more efficient. Life will not be snuffed out. It invents ways to make its own food from inorganic sources, i.e., sunlight, water, and carbon dioxide. These first food-making organisms, almost certainly at the cellular level of organization, preserve and extend the existance of life on Earth.

The primary atmosphere of Earth, that consisting mainly of helium and hydrogen, was removed by lunar tidal action. Now the secondary atmosphere, consisting of methane, ammonia, and carbon dioxide, also undergoes modification.

The processes of life soon incorporate available ammonia into protein. The methane is oxidized to carbon dioxide, which in turn is converted by photosynthesis to oxygen. The "waste" gases oxygen (from the carbon dioxide) and nitrogen (from the ammonia) enter the atmosphere in ever increasing amounts, so that the predominently nitrogen-oxygen atmosphere of today's Earth come about.

Evolution continues, driven by biological competition and physical changes such as volcanism, glaciation, and continental drift. More effective ways must be found to survive, and the less successful die to make room for the more efficient. The ability to move, to eat other living things, and to incorporate sexual reproduction into the life cycle all enhance an organism's chances of winning this desperate contest.

Individual cells reach the limit of their structural and functional potential. Some learn to work together with other cells for the common good. Soon they form colonial, and then truely multicellular, life forms.

The first multicellular formas are probably autotrophic in nature, producing their own food by photosynthesis. They have fairly low-order metabolisms, and are net producers of biologically-useful energy molecules. They continue to produce more oxygen "waste" gas then they consume, enriching the atmosphere to the point that an ozone layer is produced which further restricts the amount of cosmic and solar radiation reaching the surface. This enables both the plants and other life forms to leave the water and move onto the formerly barren landscape.

The plants develop various organ systems, which improve both their water transport and reproduction capabilities. They fairly rapidly cover the Earth, converting barren rock to soil. The Earth turns green.

In the sea is found a second kind of multicellular organism. It has an energy-intensivemetabolism, and as a net consumer of biological energy must specialize as a heterotroph. This type of organism is the animal.

Animals specialize in eating other things. Many must wear thick coats of armor to protect themselves from other animals. They too have learned tricks that help them survive. One group develops a hard structure within

the body rather than on the outside of it. Because of its location, this structure promotes growth and mobility rather than restricting it. We call it a backbone, and the animals that have it vertebrates.

The first kind of true vertebrates are the fish.In this group we find our own immediate ancestral line. It is from the backbone that other bones such as ribs and skull develop. In one group of fish, bone structures develop to strengthen the four fins.

These fish, with bony or "lobe" fins, live in muddy pools. The pools are so shallow that the bony fins are necessary for walking on the bottom at certain times of the year. These fish also develop a lung from the air-filled swimming bladder. The lung is necessary because often the pools are too foul to contain much oxygen. The fish must gasp air to survive. These adaptions to the muddy pools allow these animals to evolve into land dwellers. They will eventually evolve into us. Animals without backbones also invade the land, but are doomed by their external skeletons to always remain small.

The very processes which produced the living planet we know as Earth could and should be operative throughout our galaxy and the Universe. Our own galaxy alone has some 180×10^9 stars, and it has been estimated that these stars may share some 860×10^6 planets with conditions favorable for the development of life.[10]

What exactly are the surface conditions that are "favorable for the development of life"? The star around which the planet orbits should have a mass in the range of 0.72 to 1,43 that of Sol, our own star. Stars of this mass tend to have fairly long and stable lives, allowing time for evolution.[3] The planet itself, for various reasons, should have a mass of 0.40 to 2.35 that of Earth. [10]

Asimov and others have also postulated that, to be favorable for life, a planet must have "oceans" or at least "lakes" of solvent in which life can develop. Our own solvent, water, makes up most of our body mass. It is ideal for the kind of carbon-based life found on Earth-type planets. On planets with colder temperatures and higher pressures than that of Earth, the solvent might be liquid ammonia. This solvent has an wide temperature range (-33.4 to -77.7° C) for its liquid phase. It is ideal for carbon-based life also, although the proteins involved would most likely be of a higher nitrogen content.[2]

On planets with higher temperatures than Earth, sulfur would be the solvent of choice. Liquid from +113 to +445° C, it would be a solvent for life based on flourine-silicon as opposed to our hydrogen-carbon biochemistry. The role of carbon dioxide would of course be taken by silicon dioxide, in this case.

The amount of stellar radiation reaching the surface would be an additional factor affecting the appearance of life. The amount of radiation reaching the surface would depend on:

1. Distance of planetary surface from stellar surface.
2. Intervening astronomical bodies and atmospheric phenomena.
3. Type and age of star.
4. Planetary rotation.
5. Presence of liquid-phase solvent on the planetary surface, within which living things could further be shielded from incoming radiation.

The radiation reaching the surface must:

1. Be sufficient to warm the surface so that liquid-phase solvent is not frozen, but not so intense that the solvent is boiled away.
2. Not be so intense that the stability of enzymes, hereditary material, and other critical biochemical molecules are destroyed or compromised.

3. Provide sufficient energy to drive the biosphere in question.

These factors---stellar mass, planetary mass, presence of liquid solvent, and acceptable amounts of radiation reaching the surface---are the major parameters of favorability for life. Some 860 million planets in this galaxy alone are thought to meet all four criteria simultaneously. This translates, on a smaller scale, to some 50 habitable planets within 100 light-years of Earth.

Now that we are familiar both with the physical conditions necessary for life to begin and evolve, and the general scheme of terrestrial evolution, we have reached the limits of what is directly observable. To continue our study of extraterrestrial life we must begin to make inferences based both on observation and on theory. What things can we say are probably true, based on what we can prove?

The inferential study of life on other planets can be made scientifically valid when no statements are made that cannot be supported by knowledge that we already possess. How can we possess knowledge about a subject that no one has actually been able to observe? Knowledge in this area of investigation comes from three main sources:

1. Observation of analogies between widely divergent terrestrial taxa, when it is known that the similarities developed after the group diverged from some common ancestor. General statements based on such data are most valid when the groups are widely divergent and the analogies are quite close. One obvious example would be the wing of the insect and the bird.

2. Application of physical laws as determining factors or limiting factors for biological systems. For example, no biosphere can produce more biologically useful energy than the total energy supplied by its inorganic environment.

A simpler example might be that a streamlined organism, no matter where we go in the Universe, will always have an easier time passing through a viscous fluid than an organism of similar bulk without streamlining.

3. Application of astronomical knowledge to anticipate surface conditions on other planets.

Many will challenge this use of inference to study the unobservable. It should be noted by the skeptic, however, that similar methods were used to study relativity, anti-matter, and black holes long before the scientist was able to directly observe physical effects. On the other hand, proponents must accept the fact that hypothesis remains hypothesis until it can be proven.

With all this in mind, what are some things we can say probably are traits of all living systems? The first trait that must be identified is an acceptable definition of life itself. Most of the authors in the attached bibliography include one or more of the following characteristics as traits of life: self-replicating; able to assimilate materials from the environment; internally homeostatic; environmentally responsive; and at least partially self-repairing. The teacher in the classroom should make this definition known to his students early on in a biology course. How much more interesting it is to supplement the definitions with "crystal creatures" or "large intelligent viruses" as "specimens" from extraterrestrial biospheres that must be categorized as "living" or "non-living".

A second basic concept that can be attacked as a universal "rule" is the necessity for an organized biochemistry. This includes discussion of the role of enzymes, DNA-like master molecules, carbon and silicon atomic/molecular characteristics, etc. Biochemistry is often taught piecemeal, with little rational for the specialization of different kinds of molecules to do different kinds of biochemical jobs. Students should understand that,

no matter where one goes in the Universe, molecules intended for structural application will likely be long-chained and able to cross-link. Molecules intended for catabolic roles, on the other, are likely to be smaller and more chemically active. Once he knowsthe general"rule" for all living things, the more likely he is to understand why protein and cellulose are good structural materials while sugars are not. Once he understands that the hereditary material must be able to store information for billions of years, the better he will be able to grasp the significance of the DNA double-helix. The view of the student becomes more objective and systematic and less parochial.

Other basic themes likely to be universal in scopre are as follows:

1. Cellular basis of life. Necessary to concentrate materials separate from the environment, this is the basis of homeostatic function.

2. Active and passive transport across semi-permeable membranes. Obvious corollary to the cellular basis of life. Materials must be collected and then segregated within the cell. This is impossible if the membrane surrounding the cell is either totally permeable or totally impermeable.

3. At all levels, structure and function of organisms are totally interrelated. No organism develops structures that have no function or functions that support no structure. If they do, they are usually eliminated quickly by evolutionary competition.

4. External form matches life-style and living location. Organisms that lack symmetry, at least on the multicellular level, usually have a sessile life-style. Symmetry does not develop because no evolutionary pressure exists for it to do so. Organisms with radial symmetry are usually floaters or bottom-dwellers. Organisms with bilateral symmetry tend also to have the characteristic of cephalization, the development of a "head" with the concentration of many of the sense organs there. These tend to be active, mobile forms.

5. Evolutionary change will be evident in any biosphere. Since life itself is a result of evolutionary changes in the matter and energy of a planetary surface, the evolutionary processes will be in place prior to the actual appearance of life.

6. A physiological hierarchy, from cell to organ system, will always arise as the structure and function of organisms becomes more integrated and efficient.

7. Some organisms will specialize as autotrophs, others as heterotrophs. As populations of the two types begin to balance by birth, death, and (possibly) migration, a balanced ecology is formed.

8. Correlation of number of limbs of large organisms to planetary gravity. The number of limbs necessary to support an organism is proportional to the WEIGHT (not the mass) of the organism. On low-gravity planets, animals weigh less and will tend to have less limbs than organisms from heavy-gravity planets. Bipedalism is probably not common on heavy-gravity planets.

9. Correlation of maximum size to planetary gravity. For organisms of simlar mass/volume ratios, the smaller the planet and its gravity the LARGER the organisms can be. Conversely, the greater the planetary mass and gravity the SMALLER its organisms will tend to be.

10. Correlation of percentage of inert body mass/unit of body mass to planetary gravity. The higher the planetary gravity, the more an organism's body must develop structures to support its weight. On Earth, tissues such as wood, chiton, bone, and shell have been evolved to support other tissue. These kinds of tissue tend to be physiologically/metabolically less active than the rest of the organism, although they may act as repositories of inorganic minerals.

11. Structures analogous to wings, fins, and legs will develop in response to the need to locomote. Fins are living levers designed to push upon the medium. The paddle-like form acts to increase the effective

viscosity of the liquid the animal is swimming through.

Legs, similarly, are levers that increase the effective power of the animals muscles by providing a long moment arm between body and ground. Wings, like fins, are designed to operate in a fluid medium. They, however, operate utilizing Bernoulli's Principle to obtain lift. Thus, rather than pushing on the medium the medium in fact pushes on the wing.

12. The total biomass of the biosphere will always be limited by the amount of available energy from inorganic sources (mainly the primary star) and the necessary biological materials found in the biosphere. Any process that limits either energy or material resources limits the size of the biomass.

The classroom science teacher can apply the twelve concepts listed (as well as other developed in his own study of Biology) by having the students evaluate imaginary biospheres (either teacher-created or from commercial fiction). As the student begins to apply the rules, he indulges in higher-order learning. He is then better able to apply them to the real world around him.

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